North American Society for Trenchless Technology (NASTT)
NASTT's 2014 No-Dig Show

Orlando, Florida
April 13-17, 2014

TM1-T1-03

Focused Field Investigations for Sewer Condition Assessment with EPA SSOAP Toolbox

Srinivas Vallabhaneni, CDM Smith, Indianapolis, Indiana
Carl Chan, CDM Smith, Indianapolis, Indiana
Ariamalar Selvakumar, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Urban Watershed Management Branch, 2890 Woodbridge Avenue (MS-104), Edison, New Jersey

1. ABSTRACT

The Nation's sanitary sewer infrastructure is aging, and is currently one of the top national water program priorities. The U.S. Environmental Protection Agency (EPA) developed the Sanitary Sewer Overflow Analysis and Planning (SSOAP) Toolbox to assist communities in developing SSO mitigation plans including sewer capacity and condition assessment.

The SSOAP Toolbox contains a suite of integrated computer software tools. It can serve as the foundation of wastewater collection system assessment by analyzing monitored flow data to prioritize where to inspect for condition assessment, and to evaluate the performance of rehabilitation activities.

The current state of technology for assessing the condition of sewer systems utilizes *rather* time consuming and expensive field investigations employing the conventional closed circuit television or newer emerging technologies (e.g., sonar, laser, ultrasonic, and infrared). The rainfall derived infiltration and inflow prediction methodology employed in the SSOAP Toolbox offers an effective and less costly means to design a focused condition assessment program and maximize the success of field investigation efforts.

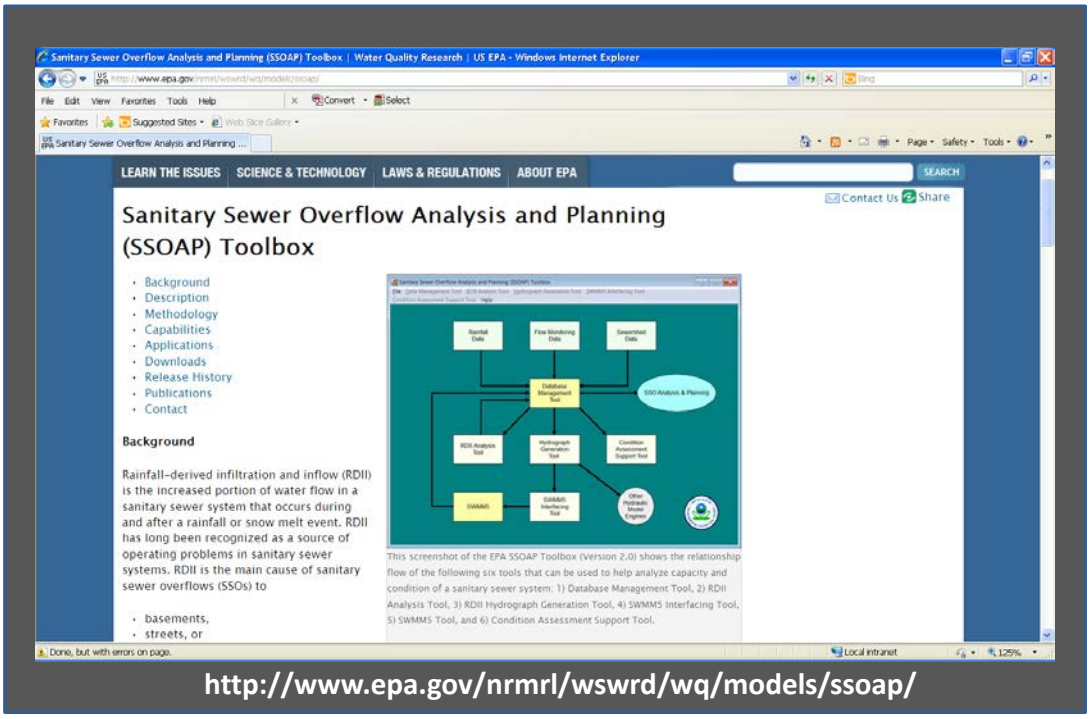
In this technical paper, the authors discuss how SSOAP fits into the overall asset management framework and highlights the use of SSOAP to design focused field investigation plans as part of a sanitary sewer condition assessment and subsequent rehabilitation evaluation.

2. INTRODUCTION

Aging water infrastructure is currently one of the top national water program priorities, and is one of the top priorities of the U.S. Conference of Mayors. The Nation's sanitary sewer infrastructure is aging, with some sewers dating back more than 100 years. A properly designed, operated and maintained sanitary sewer system is meant to collect and convey all of the sewage that flows into a wastewater treatment plant. However, occasional unintentional discharges of raw sewage from municipal sanitary sewers to streets, private property, basements and receiving waters—called sanitary sewer overflows (SSOs)—occur in many systems.

Rainfall-derived infiltration and inflow (RDII) into sanitary sewer systems has long been recognized as a major source of operating problems that cause poor performance of many sewer systems including SSOs. The extent of infiltration also correlates with the condition of aging sewers.

In 2002, to assist communities in developing SSO mitigation plans, the EPA entered into a cooperative research and development agreement (CRADA) with CDM Smith Inc., to develop a public domain computer toolbox and associated technical reports. The toolbox is named SSO Analysis and Planning (SSOAP). CRADA efforts were completed in 2008. During EPA's Aging Water Infrastructure (AWI) research program in 2010 (EPA, 2010) (http://www.epa.gov/awi/pdf/600f09042.pdf), the SSOAP Toolbox was determined to be a critical tool in wastewater collection system analysis, enabling users to analyze monitored flow data to prioritize where to inspect, monitor, and assess the performance of rehabilitation. Consequently, EPA and CDM Smith Inc. further enhanced the SSOAP Toolbox by adding a new Condition Assessment Support Tool, which enables users to develop focused sewer condition assessments and evaluations of completed improvements. This enhancement effort was completed in 2013 and the latest version of the SSOAP Toolbox and related technical reports are available on the EPA SSOAP Toolbox website depicted on Figure 1 (*EPA 2013*).


Sanitary Sewer Overflow Analysis and Planning (SSOAP) Toolbox | Water Quality Research | US EPA - Windows Internet Explorer
LEARN THE ISSUES
SCIENCE & TECHNOLOGY
LAWS & REGULATIONS
ABOUT EPA
SEARCH
Contact Us
Share
Sanitary Sewer Overflow Analysis and Planning (SSOAP) Toolbox
Background
Description
Methodology
Capabilities
Applications
Downloads
Release History
Publications
Contact
Background
Rainfall-derived infiltration and inflow (RDII) is the increased portion of water flow in a sanitary sewer system that occurs during and after a rainfall or snow melt event. RDII has long been recognized as a source of operating problems in sanitary sewer systems. RDII is the main cause of sanitary sewer overflows (SSOs) to
basements,
streets, or
This screenshot of the EPA SSOAP Toolbox (Version 2.0) shows the relationship flow of the following six tools that can be used to help analyze capacity and condition of a sanitary sewer system: 1) Database Management Tool, 2) RDII Analysis Tool, 3) RDII Hydrograph Generation Tool, 4) SWMM5 Interfacing Tool, 5) SWMM5 Tool, and 6) Condition Assessment Support Tool.
http://www.epa.gov/nrmrl/wswrd/wq/models/ssoap/
Figure 1 – EPA SSOAP Toolbox Website.

3. SSOAP TOOLBOX OVERVIEW

The SSOAP Toolbox contains a suite of integrated computer software tools which fit well in to the overall sewer asset management framework. It can serve as the foundation of wastewater collection system capacity and condition assessments. This toolbox includes EPA's Storm Water Management Model Version 5 (SWMM5) (*EPA, 2013*) for performing dynamic routing of flows through the sanitary sewer system for capacity assessment. The RDII prediction methodology employed in the toolbox offers an effective means to design a focused sewer condition assessment program and maximize the success of field investigation efforts. Also, it provides an effective means to assess the post-rehabilitation performance of the sewer system using the pre- and post-sewer capacity analysis. Figure 2 shows the overall structure of the SSOAP Toolbox.

The SSOAP Toolbox contains six functional tools designed to support a range of technical analyses in support of SSO mitigation and sewer condition assessment efforts, which include:

1. Managing and analyzing flow monitoring and rainfall data
2. Determining RDII characteristics
3. Prioritizing the sewershed for sewer condition assessment, rehabilitation and RDII source reduction
4. Evaluating performance of sewer rehabilitation improvements based on pre- and post- improvement RDII analysis
5. Performing sanitary sewer capacity assessment and improvement analysis by:
    a. Evaluating RDII related SSOs using SWMM5
    b. Managing SWMM5 hydraulic simulation results

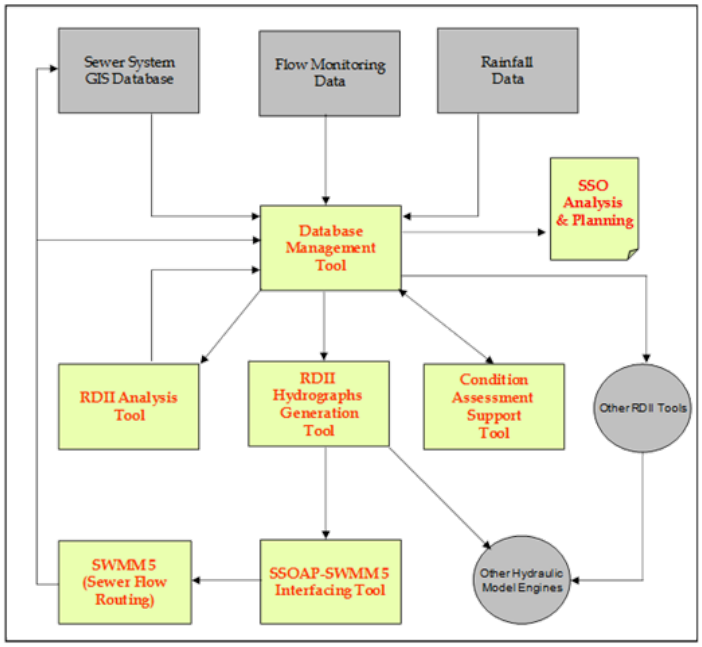


Figure 2 – SSOAP Toolbox Overview.

RDII Methodology Used in SSOAP

The three major components of wet-weather wastewater flow into a sanitary system − base wastewater flow (BWF), groundwater infiltration (GWI), and RDII − are illustrated in Figure 3 and are discussed further.

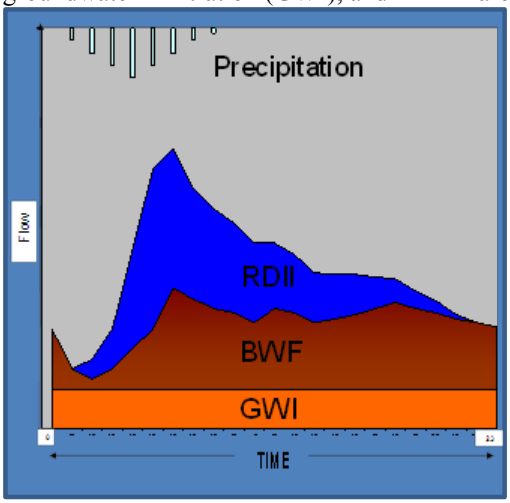


Figure 3 – Three components of wet-weather wastewater flow during a precipitation event.

BWF and GWI

BWF is the residential, commercial, institutional, and industrial flow that discharges to a sanitary sewer system for collection and treatment. GWI represents the infiltration of groundwater that enters a collection system through leaky pipes, pipe joints, and manhole walls. GWI varies throughout the year, often trending higher in late winter and spring as groundwater levels and soil moisture levels rise, and subsiding in late summer or after an extended dry period. Together, GWI and BWF comprise the dry-weather flow (DWF) that occurs in a sanitary sewer system. Because the determination of GWI and BWF components of DWF is not an exact science, various assumptions related to the water consumption return rates and wastewater monitored during early morning hours are typically used to help estimate these flows components.

RDII

In most systems, RDII is the major component of peak wastewater flows during wet weather and is typically responsible for capacity-related SSO problems and basement backups. Snowmelt may also contribute to RDII flows. Figure 4 depicts various pathways of RDII into sanitary sewer systems. "Inflow" is the water that enters a sanitary sewer system directly via depressed manhole lids and frames, downspouts, sump pumps, foundation drains, areaway drains, and cross-connections with storm sewers. Although direct connections such as downspouts, sump pumps, foundation drains, and areaway drains are no longer common design practices, they still exist and contribute to inflow in many older systems. Inflow typically occurs shortly after a rainfall starts and stops quickly once it stops. Inflow is typically the major component of the RDII peak flow.

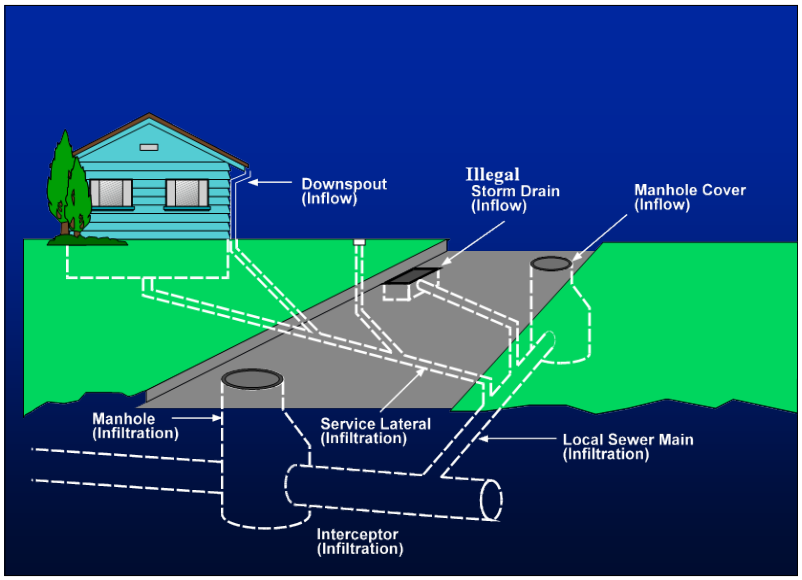


Figure 4 – Pathways of infiltration and inflow into sanitary sewer systems.

Rainfall-derived infiltration refers to rainfall runoff that filters through the soil before entering a sanitary sewer system through damaged pipe sections, leaky joints, or poor manhole connections. These defects can occur in both the public right-of-way portions of the sanitary sewer system or in individual service laterals on private property. Infiltration processes typically extend beyond the end of rainfall and take some time to recede to zero after the storm event. A system may experience a fast RDI response, a slow RDI response, or both.

Various factors control RDII responses in addition to the rainfall (volume, intensity, and duration) and antecedent moisture conditions, including depth to groundwater, depth to bedrock, land slope, number and size of sewer system defects, type of storm drainage system, soil characteristics, and type of sewer backfill. Further, RDII responses can vary greatly due to spatial rainfall distributions over a sewershed. The complex nature of RDII sources and its pathway to the sanitary system poses a significant technical challenge to accurately and reliably predict RDII over a range of rainfall and soil moisture conditions. EPA published a review of various RDII prediction methods and selection of a RDII methodology for implementation in the SSOAP Toolbox (*EPA, 2008*). The RTK method depicted in Figure 5, as used in SWMM5 (*EPA, 2013*), is also implemented in SSOAP. This method uses three triangular unit hydrographs to represent the various ways that precipitation contributes to RDII.

As shown on Figure 5, the shape of each of three unit hydrographs is defined by three parameters: R, T, and K. R represent the fraction of rainfall falling on the sewered area that enters the sewer system as RDII. T is the time to the peak RDII flow in hours, and K is the ratio of the time of recession to the time of peak. The RDII volumes corresponding to three unit hydrographs are designated as R_1 (fast response), R_2 (medium response), and R_3 (slow response). The sum of R_1, R_2, and R_3 equals the total R-value for the storm event that represents the total fraction of rainfall over the sewershed that entered the sewer system. A high R_1 value indicates that the RDII is primarily inflow driven. If more of the total R-value is allocated to R_2 and R_3, this indicates that the RDII is primarily infiltration driven. In addition, this approach provides means to estimate the groundwater infiltration to sewers that is not directly related to rainfall. This knowledge is useful during a sewer system evaluation survey to determine whether a point repair or a comprehensive rehabilitation approach is more suitable.

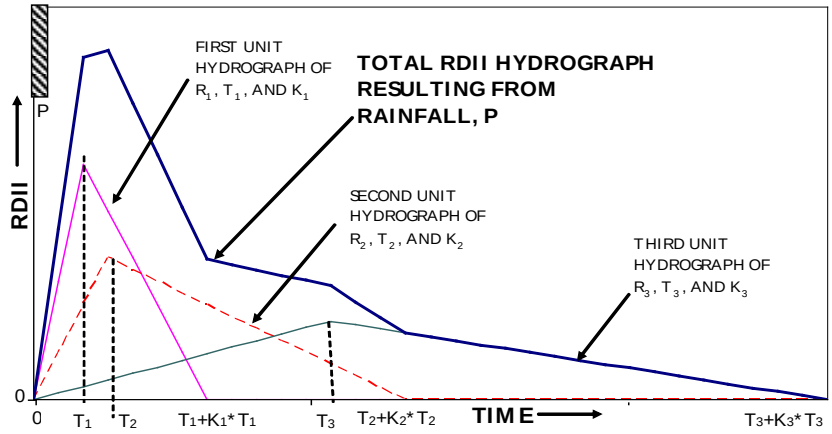


Figure 5 – The RTK Method and parameters.

This paper focuses on the Condition Assessment Support Tool and how SSOAP fits into the overall Asset Management framework. Previous publications (*Lai et al., 2007: Vallabhaneni et al., 2008 and 2011, EPA, 2007, 2008 and 2012*) documented the USEPA efforts in SSOAP development, technical basis for RDII prediction method implemented, detailed description of all six functional tools within the SSOAP Toolbox and their applications. The online SSOAP Toolbox user's manual also guides users on proper tool usage and provides guidelines for a range of applications (*EPA, 2007 and 2013*).

4. CONDITION ASSESSMENT SUPPORT TOOL

The current state of technology for assessing the condition of sewer systems is by visual examination using rather time consuming and expensive field investigations that employ the conventional closed circuit television or newer emerging technologies (e.g., sonar, laser, ultrasonic, and infrared). The RDII prediction methodology in the SSOAP Toolbox offers an effective means to design a focused condition assessment program and maximize the success of field investigation efforts. The distribution of R-value (i.e. the percent of rainfall that enters a sanitary sewer system) is useful for establishing the relative subbasin priorities and can be used to support the condition assessment and subsequent system rehabilitation efforts. This knowledge of subbasin priorities will minimize the guess work in designing more focused field investigation efforts.

The condition assessment support tool in the SSOAP Toolbox can help users in developing priorities among sub-sewersheds and comparing post-rehabilitation estimates with pre-rehabilitation conditions. There are two major functions in this tool:

1. Obtains sub-sewersheds' RTK parameters from the Database Management Tool and enables users to compare them via graphics and tables. This information can be used to prioritize sub-sewersheds, design focused field investigations, and subsequent sewer rehabilitation plans.

2. Obtains sub-sewersheds' RTK parameters under pre- and post-rehabilitation conditions from the Database

Management Tool and enables users to correlate data via graphics and tables. Users can then assess the effectiveness of sewer rehabilitation programs.

4.1 Sub-sewershed Prioritization for Condition Assessment Field Investigations

The Condition Assessment Support Tool uses the RDII analysis results stored in the Database Management Tool as the basis to generate information for sub-sewershed prioritization. Using the spatial distribution of R-values, users can prioritize the tributary areas' condition assessment and subsequent system rehabilitation. Users can apply a range of RDII parameters stored in the Database Management Tool, such as Total-R, R1, R2, and R3, to prioritize the sub-sewersheds and identify specific types of field investigation needs. Other parameters, such as peak RDII flow rate/sub-sewershed area and RDII volume/length of sewer in sub-sewersheds, can also be used as criteria to assess the priorities. The following example scenarios are presented to demonstrate the Condition Assessment Support Tool's capability to generate information to help establish sub-sewershed prioritization based on the user's preference/criteria (*EPA, 2012 and 2013*).

Example Scenario 1: Sub-sewershed prioritization analysis results based on total RDII: Figure 6 shows sub-sewershed prioritization based on RDII in terms of Total-R value. Considering that each sub-sewershed is likely to experience a range of Total R-values during a flow monitoring period, the SSOAP Toolbox user can select the average or median of the observed R-values for this analysis. Alternatively, users can display the observed maximum R-value for the sub-sewershed prioritization analysis. Figure 6 shows an analysis performed with the average Total R-value and observed RDII from the same wet-weather events between sub-sewersheds. The analysis shown in Figure 6 can guide the user to prioritize RDII investigation and reduction efforts focusing on sub-sewersheds with high average total R-value.

Example Scenario 2: Sub-sewershed prioritization analysis results based on total RDII and breakdown of inflow and infiltration components (R1, R2, and R3-values): Figure 7 extends the Scenario 1 analysis, showing sub-sewershed prioritization based on observed RDII in terms of Total-R value and distribution R1, R2, and R3 components. This information is needed to determine which type of field investigation (inflow- based or infiltration-based) should be conducted. *If a sub-sewershed's RDII response is dominated by inflow (R1), conducting extensive internal inspections will likely provide less useful information to design system improvements because the problem is likely to be a capacity issue vs. sewer rehabilitation.* This example shows there is a significant portion of RDII in sub-sewershed FM18 due to infiltration components (R2 and R3 responses). The Condition Assessment Support Tool can use average, median, or maximum R-values for conducting this analysis, similar to Example Scenario 1.

Example Scenario 3: Sub-sewershed prioritization analysis results based on fast response – Inflow dominance (R1-value): The user can select to analyze the sub-sewersheds based on the inflow component (R1), as shown in Figure 7. The example analysis presented in Figure 8 indicates FM9 had the highest inflow and should have top priority for field investigation, even though it actually had the lowest total RDII compared to other sub-sewersheds.

Example Scenario 4: Sub-*sewershed* prioritization analysis results based on medium response – foundation/yard drains (R2-value): Figure 9 shows how the user can analyze sub-sewersheds based on medium RDII response (R2 values), which typically result from foundation and yard drain discharges. This analysis enables users to determine private property RDII contributions and correction needs, such as footing drain disconnections.

Example Scenario 5: Sub-sewershed prioritization analysis results based on slow response – infiltration dominance (R3-*value*): The user can perform the prioritization analysis with focus on the infiltration component represented by the R3-value, as shown on Figure 10. The results from this analysis help users design field investigation efforts that focus on internal sewer inspections to locate the poor sewer conditions defects that contribute to excessive infiltration.

Example Scenario 6: Sub-sewershed prioritization analysis results based on medium and slow response (R2-plus R3-value): Figure 11 shows sub-sewershed prioritization analysis using combined components of medium and slow responses (R2 plus R3). This analysis focuses on an overall infiltration-dominated RDII component, excluding the fast (inflow) response. For sewer systems with nominal medium response, this analysis offers limited value.

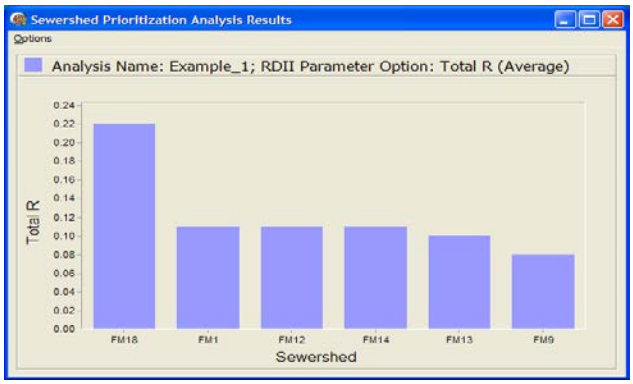


Figure 6 – Example Scenario 1 – Sub-sewershed prioritization analysis based on total RDII

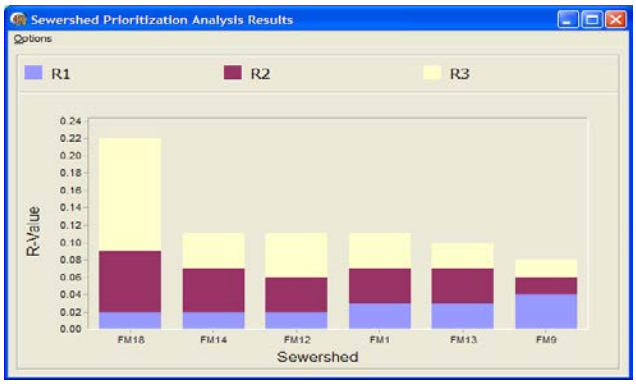


Figure 7 – Example Scenario 2 – Sub-sewershed prioritization analysis based on total RDII and breakdown of inflow and infiltration components (R1, R2, and R3 values)

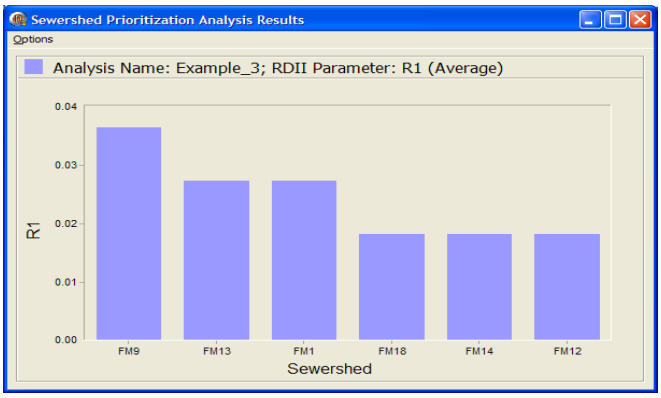


Figure 8 – Example Scenario 3: Sub-sewershed prioritization analysis based on fast response – inflow dominance (R1 value).

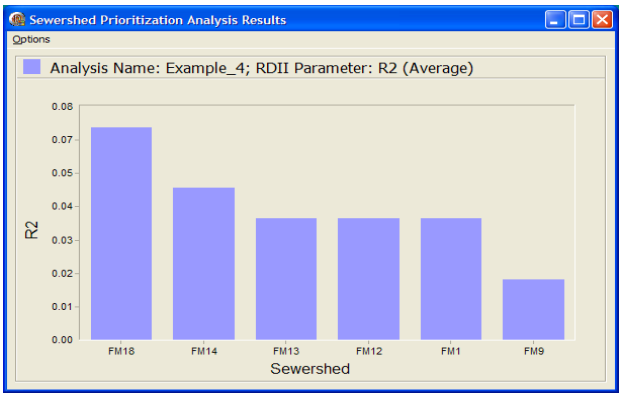


Figure 9 – Example Scenario 4: Sub-sewershed prioritization analysis based on medium response (R2 value).

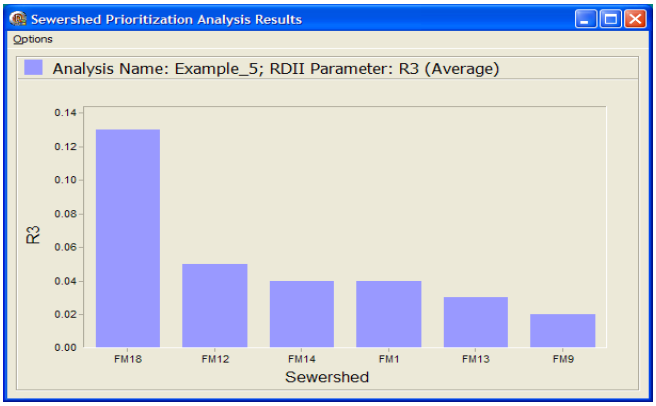


Figure 10 – Example Scenario 5: Sub-sewershed prioritization analysis based on slow response – infiltration dominance (R3 value).

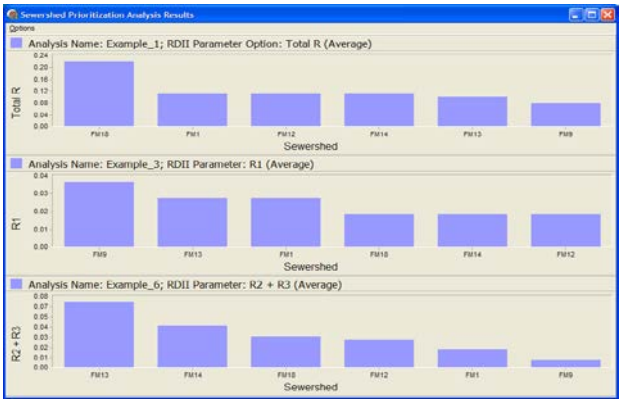


Figure 11 – Example Scenario 6: Sub-sewershed prioritization Analysis based on medium and slow response (R2 plus R3).

Example *Scenario* 7: Sub-sewershed prioritization analysis results based on RDII volume per linear feet of sewer): Figure 12 presents prioritization analysis with RDII volume/length of sewer in sub-sewersheds as the key parameter and shows sub-sewershed FM 13 as higher priority. This approach offers a direct correlation of RDII reduction to the length of sewer rehabilitated.

Example Scenario 8: Sub-*sewershed* prioritization analysis results based on peak RDII flow rate per acre: Figure 13 depicts the peak RDII flow rate/sub-sewershed area as the RDII parameter to prioritize sub-sewersheds and identifies sub-sewershed FM 18 as the higher priority with this user preference/criteria.

The analyses shown in examples 1 through 8 help users prioritize sub-sewersheds for further analysis and identify appropriate field investigation techniques. For example:

- Figure 6 (average total-R) shows that sub-sewershed FM18 experiences the highest level of RDII when compared to other sewersheds. However, Figure 8 (average R1) suggests that there are other sub-sewersheds with more inflow than FM18.
- Figure 11 (average R2 + R3) and Figure 9 (average R2) indicate that FM18 has significant infiltration likely from foundation and yard drain conditions, which suggests poor sewer conditions.
- Finally, Figure 7 shows the breakdown of R1, R2, and R3, suggesting that that the FM18 sewershed should be top priority for field investigation with a focus on sources and quantity of excessive infiltration.

Users can use median values or peak values from the RDII analysis results vs. using average values for the above listed prioritization analyses. The Condition Assessment Support Tool also allows the user to display up to three prioritization analyses together for comparison. Figure 14 shows three prioritization analyses, i.e., Total R-value (RDII), R1 (inflow), and R2 + R3 (infiltration) combined. This comparative analysis points how the higher priorities can change among FM 18, FM9 and FM 13 based on the selected criteria.

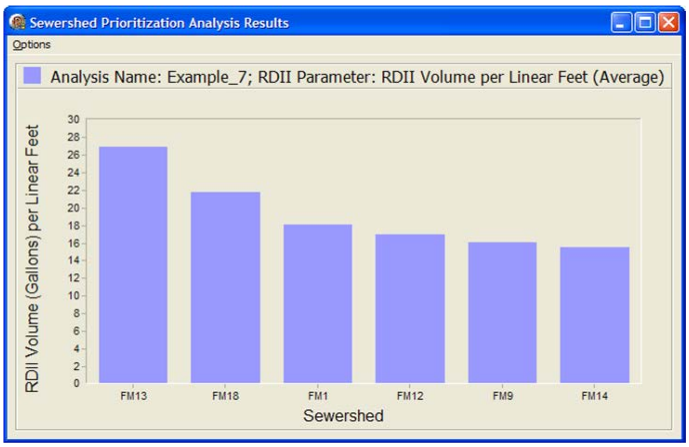


Figure 12 – Example Scenario 7 – Sub-sewershed prioritization analysis based on RDII volume per linear feet of sewer.

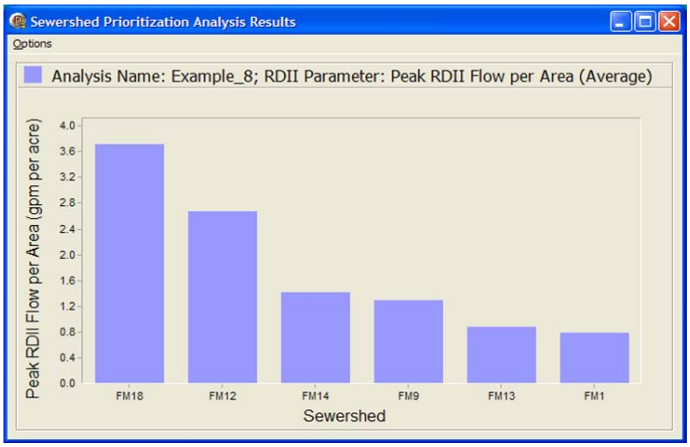


Figure 13 – Example Scenario 8: Sub-sewershed prioritization analysis based on peak RDII flow rate per area.

Figure 14 – Example of using 3 sub-sewershed prioritization analyses to support field investigation decision-making.

The above discussion concludes that the Condition Assessment Support Tool can assist in: assessing the relative magnitude of inflow and infiltration for each sub-sewershed; Establish priorities using a wide range of RDII parameters and evaluation criteria; and guiding users to select appropriate field investigation techniques for sewer condition assessment.

4.2 Pre- and Post- Sewer Rehabilitation RDII Correlation Analysis

The Condition Assessment Support Tool is also designed to help SSOAP Toolbox users assess the effectiveness of sewer rehabilitation by comparing RDII estimates from two sub-sewersheds (control and rehabilitation) obtained from pre-rehabilitation and post-rehabilitation periods. The control sub-sewershed is a sewered area, ideally nearby, similar in age, size, land-use, and pipe materials to a sub-sewershed being studied with post-rehabilitation conditions. The control area must not have had any rehabilitation work because it will be used to compare how RDII is reduced as a result of system rehabilitation and other improvements.

The Condition Assessment Support Tool helps users establish the RDII reduction trends by developing a linear relationship between observed R-value in the rehabilitated sub-sewershed and observed R-value in control sub-sewershed under pre- and post-rehabilitation conditions. The more data available (e.g., long-term flow monitoring for one year or more vs. short-term monitoring for two to four months), the more reliable the measure of RDII reduction trends with increased statistical significance. The linear regression methods included in the Condition Assessment Support Tool can help establish general trending of RDII reductions. Users that have the long-term flow meter data and RDII analysis results and would like to study non-linear relationships can export RDII parameters in a tabular format for pre- and post-flow monitoring periods for use in their statistical software package of choice.

Figures 15 and 16 show two examples of RDII correlations for pre- and post-rehabilitation conditions for test sub-sewersheds with RDII estimates for respective control sub-sewersheds. The X-axis represents R-values for the control area and the Y-axis represents rehabilitated area. Each triangle in the figure represents an actual R-value for both control and rehabilitated areas observed during the same wet-weather event during pre- and post-rehabilitation flow monitoring periods. Each line represents a linear regression between the R values of the rehabilitated area and the control area. The RDII reduction trending is estimated by determining the difference in the slopes of the regression lines for pre- and post-rehabilitation conditions. As shown in Figures 15 and 16, RDII response in a sewershed can vary significantly under different hydrological conditions. Therefore, it is important to obtain a range of rainfall and flow monitoring data to characterize a range of rainfall conditions, antecedent moisture conditions, and RDII response in the sanitary sewer system.

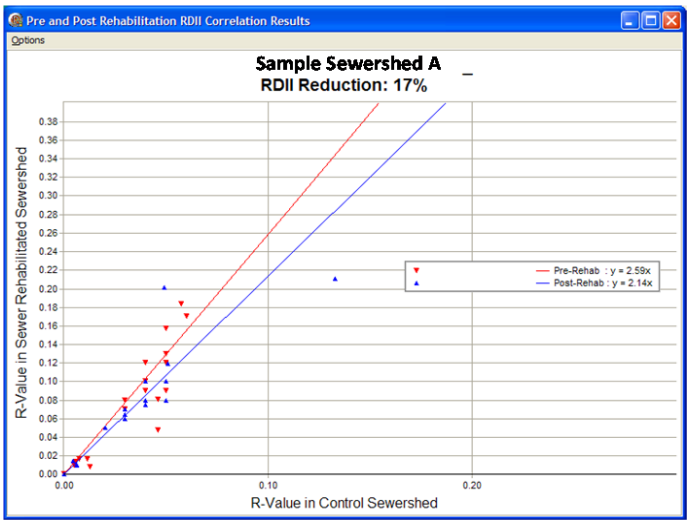

Pre and Post Rehabilitation RDII Correlation Results
Options
Sample Sewershed A
RDII Reduction: 17%
R-Value in Sewer Rehabilitated Sewershed
R-Value in Control Sewershed
Pre-Rehab : y = 2.59x
Post-Rehab : y = 2.14x

Figure 15 – Example correlation of RDII between rehabilitation and control sub-sewershed – Example 1.

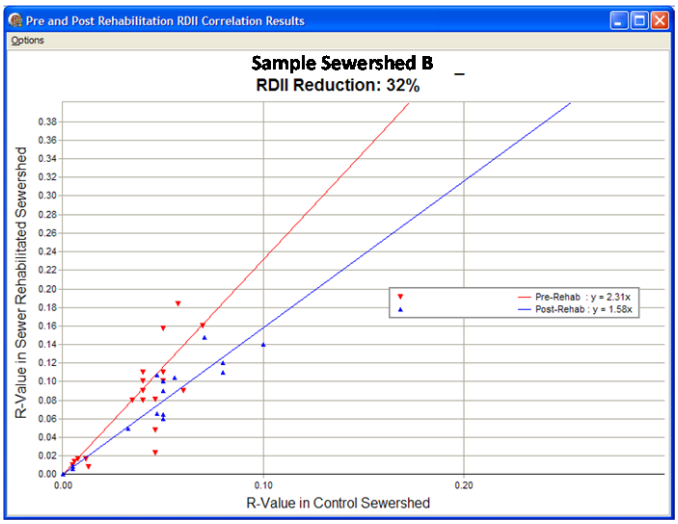

Pre and Post Rehabilitation RDII Correlation Results
Options
Sample Sewershed B
RDII Reduction: 32%
R-Value in Sewer Rehabilitated Sewershed
R-Value in Control Sewershed
Pre-Rehab : y = 2.31x
Post-Rehab : y = 1.58x

Figure 16 – Example correlation of RDII between rehabilitation and control sub-sewershed – Example 2.

5. CONCLUSION

The RDII prediction methodology employed in the SSOAP Toolbox offers an effective means for designing a focused condition assessment program and maximizing the success of field investigation efforts. The SSOAP

Toolbox offers users a single environment for analyzing RDII, capacity assessment, and prioritizing where to inspect, monitor, and assess the success of rehabilitation activities.

6. DISCLAIMER

Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the EPA. Any mention of products or trade names does not constitute recommendation for use by the EPA.

7. REFERENCES

Lai, F.-h.; Vallabhaneni, S.; Chan, C.; Burgess, E.; Field. R. (2007) A Toolbox for Sanitary Sewer Overflow Analysis and Planning (SSOAP) and Applications. Proceedings of Water Environment Federation.

U.S. Environmental Protection Agency (EPA) (2007) *Computer Tools for Sanitary Sewer System Capacity Analysis and Planning*, EPA/600/R-07/111.

U.S. Environmental Protection Agency (EPA) (2008) *Review of Sewer Design Criteria and RDII Prediction Methods*, EPA/600/R-08/010.

U.S. Environmental Protection Agency (EPA) (2012) *SSOAP Toolbox Enhancements and Case Study*, EPA/600/R-12/690.

U.S. Environmental Protection Agency (EPA) (2013) Sanitary Sewer Overflow and Planning (SSOAP) Toolbox. http://www.epa.gov/nrmrl/wswrd/wq/models/ssoap/

U.S. Environmental Protection Agency (EPA) (2013) Stormwater Management Model; http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/

Vallabhaneni, S.; Lai, F.-h.; Chan, C.; Burgess, E.; Field. R. (2008) SSOAP − A USEPA Toolbox for SSO Analysis and Control Planning; Proceedings of the World Water and Environmental Resources Congress; EWRI; May 12-16; Honolulu. HI.

Vallabhaneni, S.; Chan, C.; Selvakumar, A. (2011) EPA SSOAP Toolbox Application for Condition and Capacity Assessment of Wastewater Collection Systems; Collection Systems Conference, Water Environment Federation; June 12-15; Raleigh, NC.